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ROYAL SOCIETY.

REPORTS OF THE GRAIN PESTS (WAR) COMMITTEE.

No. 5.

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July, 1919.

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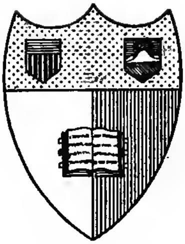

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ON THE PREVENTION OF HEATING IN WHEAT BY MEANS OF AIR-TIGHT STORAGE.

By ARTHUR DENDY, D.Sc., F.R.S., Professor of Zoology in the University of London, and

H. D. ELKINGTON, B.Sc., F.I.C.

In connection with our conclusions [Dendy, 1918, Dendy and Elkington, 1918] as to the efficacy of air-tight storage as a means of avoiding the ravages of destructive insects the question has been raised as to the effect of such treatment upon the wheat. more especially from the point of view of the process known to the trade as "heating." It is well known that when wheat, or any other cereal, is stored by the methods in ordinary use it is necessary to keep a watchful eye upon the temperature of the grain and as soon as it rises to a certain degree to turn it over or run it into a fresh silo in order to cool it. The danger is, of course, emphasized in warm weather and when the grain contains a relatively high percentage of moisture, which may either be present initially, as in English wheat, or may be absorbed from a moist atmosphere. The trade has therefore become accustomed to regard abundant ventilation as a necessary condition of successful storage of grain in bulk, and may very naturally look with suspicion upon any proposal to dispense with ventilation altogether. Nevertheless it is obvious that, inasmuch as the "heating" is due to processes of fermentation which themselves depend upon the presence of oxygen, the total deprivation of oxygen must result in the prevention of heating.

As to the actual occurrence of heating and its effect upon the grain when the latter is stored in bulk in receptacles that are not hermetically sealed we may refer to a paper by J. W. T. Duvel [1909], who records his observations upon 5,550 bushels of shelled corn having a moisture content of 17 to 18 per cent., stored in a 65-foot bin at Baltimore, and left without "running" from February 17–18 to April 27, 1909. At the end of this time heating had progressed at the top of the bin until the corn eight inches below the surface had become hot and sour, with a temperature of 133° F., the initial temperature, when the bin was filled, having been 36° to 40° F. The only marked increase in temperature took place in the 6 or 7 feet of corn at the top of the bin, the temperature 12 feet down being 51° to 56° F. and in the lower part of the bin 39·5° to 41·5° F. These observations clearly suggest that the heating was confined to those parts of the bin to which fresh supplies of air could gain access.

As to the correlation between heating and the moisture content of the grain we may quote first from the work of Duvel and Duval [1913], who made observations on cars loaded with shelled corn and containing on an average about 1,193 bushels. Between April 14 and May 11, 1910, in corn with a moisture content of 16·7 per cent. the temperature rose from 58° to 62° F., with a moisture content of 17·8 per cent. it rose from 54° to 82·5° F., with 18·6 per cent. from 52° to 84° F., but with 19·8 per cent. of moisture it rose from 58° to 139·5° F.

From observations extending over a year Bailey [1917] concluded that hard spring wheat of reasonable plumpness containing less than 14·5 per cent. of water is not likely to heat when stored under normal conditions in a temperate climate, while similar wheat containing 15·5 per cent. or more is practically certain to heat.

Saxby [1917–18] states that foreign wheats with 13·5 per cent. of water will with care and attention keep for long periods in silos, and those with 11 per cent. and under require little or no attention, but moist English wheat with 15 to 19 per cent. (average 17 per cent.) will not keep sound in warm weather for periods of even a few weeks in the best-appointed silos ever made. He suggests that the Government should store wheat by mixing the English of high moisture content with Indian or Australian of low. In 14 days the moisture would adjust itself to about 13·5 per cent. and the wheat could be kept for long periods.

A little more than twelve months ago an important memoir was published by Bailey and Gurjar [1918], who attribute the rise of temperature in stored wheat to the "respiration" of the grain. It appears to us unfortunate that the term "respiration" should have come into use in this connection, for it is obvious that what is really meant is fermentation and not respiration in the strictly physiological sense. The authors conclude that "spontaneous heating in damp grain is occasioned by the biological oxidation of dextrose and similar sugars, chiefly in the germ or embryo of the kernel," and thus find themselves in accord with the results of earlier investigators. They point out that increase of temperature accelerates the rate of "respiration" until 55° C is reached. "As the temperature rises the diastatic action upon starch increases. A point is reached, however, at which the enzyme activity diminishes." They also note that accumulation of carbon dioxide in the respiration chamber decreases the rate of respiration and that respiration is reduced in an oxygen-free atmosphere, the ratio to that occurring in a normal atmosphere being about 1 to 2·5.

It would seem to follow logically from these observations that air-tight storage should at least greatly reduce the danger from heating, but it remained to prove this by direct experiment and for this purpose the investigations described in the present report were undertaken.

In order to avoid, as far as possible, the dissipation of heat when experimenting with only small quantities, we made use of thermos flasks. Approximately equal quantities of wheat (about 400 grams) were placed in each of two flasks, together with a thermometer. One of the flasks was sealed and the other lightly plugged with cotton wool. In both experiments the moisture content of the wheat was artificially raised in order to increase the liability to heating. In the first the flasks were kept in an incubator in order to expedite the heating process, in the second they were kept at room temperature.

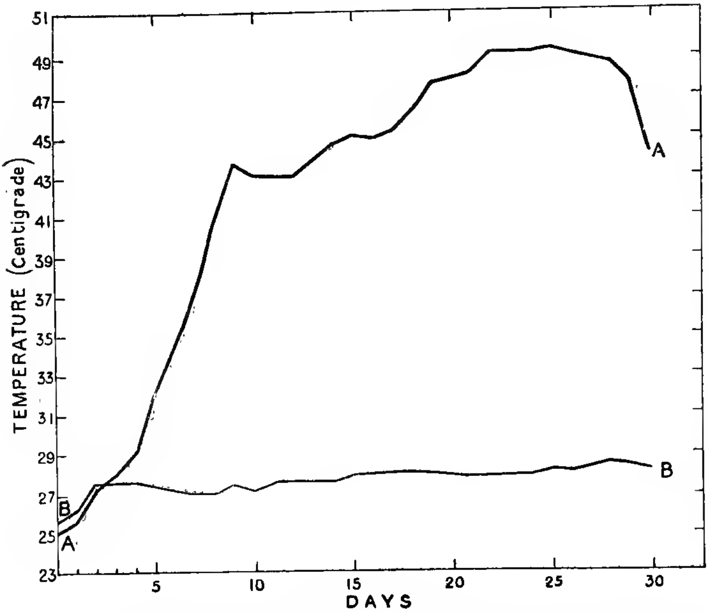
Experiment I.

On February 6, 1919, 800 grammes of mixed English wheat were weighed out and sufficient water added to bring the moisture content up to 20·7 per cent. (by analysis). The damped grain was thoroughly mixed and kept in an incubator at about 30° C. for four days in a closely stoppered bottle to allow the moisture to become evenly distributed through the grain. On February 10 the bottle was removed from the incubator and the stopper blew out, indicating the development of considerable gas pressure. The grain at this time showed no rise in temperature, indeed the temperature appeared to be slightly below that of the incubator, the discrepancy being probably due to the fact that the temperature of the upper part of the incubator, where the incubator thermometer was placed, was actually higher than that of the lower part, in which the grain was. The grain was swollen but showed no sign of germination. It was turned out of the bottle, thoroughly mixed and immediately filled into the two thermos flasks, filling them to within about 1 inch from the top. The flasks were then placed in the same incubator and their temperature recorded daily, except Sundays. The thermometers in the flasks were placed so that the bulb remained in the upper part of the wheat, the lower extremity being about 2½ inches from the top of the flask. The two thermometers did not quite agree in calibration, that in the open flask reading about 0·5° C. higher than the other.

A sample of the moist incubated wheat, taken at the time when the flasks were filled, was tested for carbon dioxide production and it was found that 50 grams of wheat sealed for 24 hours at about 30° C. yielded 0·121 grams of CO_2. It was no doubt the evolution of carbon dioxide that caused the gas-pressure referred to above.

The temperature records of the two flasks are shown in the accompanying curves (Fig. 1, A, B). It will be seen that in the sealed flask (B) the temperature of the wheat, having once risen to that of the incubator, remained almost constant throughout the whole of the period through which the experiment continued. In the ventilated flask (A), on the other hand, the temperature rose rapidly to 43·8° C., then fell slightly* and rose again more slowly to a maximum of 49·4° C., after which the curve began to fall again (Fig. 1).

FIG. 1.



The two flasks were opened on March 13 and the contents examined. In the sealed flask the wheat, though very damp, looked bright and clean, and, with the exception of one or two grains at the bottom of the flask, was quite free from mould or mildew. It was only slightly caked and had a slightly acid smell. The heated wheat in the ventilated flask presented a marked contrast. It had a very musty smell, was badly caked, mouldy on the surface, rotten and black in the lower layers, and very damp. In neither flask was there any sign of germination and a germination test made on wheat from the sealed flask gave no result in nine days, the wheat rapidly going mouldy. The original germination value of the sample was 93 per cent.

Experiment II.

On March 17, 1919, 800 grammes of hard Canadian wheat (No. 1 North Manitoba) was soaked for several hours and then spread out to dry overnight at room temperature. The moisture content on the following day was determined and found to be 34·95 per cent. The damp grain was filled into two thermos flasks as before, the one being lightly plugged with cotton wool and the other hermetically sealed. The two thermometers used this time agreed with one another to within one-fifth of a degree (Centigrade), and as before the bulbs were placed in the upper part of the wheat. The flasks were then packed in cotton wool in a large glass vessel and kept in a cupboard in the laboratory throughout the experiment, which lasted for 76 days. On two occasions, owing to the advent of cold weather, the mercury in the sealed flask sank out of sight (below 12° C.) and remained there for some days, but the interruptions in the curve thus caused (*see* Fig. 2, B) are obviously of no importance, as the temperature of this flask throughout closely followed that of the room (Fig. 2, C) in which the experiment was conducted, there being, as in the first experiment, no indication of heating in the wheat.

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* Probably more than is shown in the curve, for a Sunday intervened, on which the temperature was not taken, whence the horizontal line in the curve at this point.

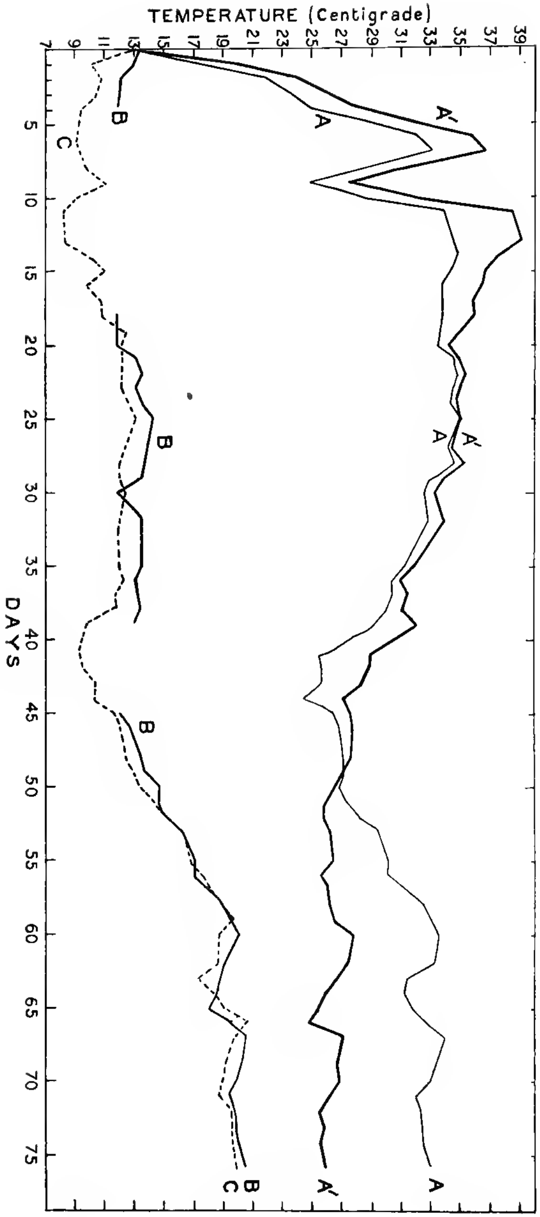
In the ventilated flask, on the other hand (Fig. 2, A), the temperature at once began to shoot up and continued to rise steadily until it reached 33·2° at the end of the 7th day. It then fell abruptly, reaching 24·8° at the end of the 9th day, when it commenced to rise again, attaining a maximum of 35·2° at the end of the 25th day. It then began to fall pretty steadily, reaching 24·6° at the end of the 44th day. At about this time the temperature of the room began to rise considerably, causing a corresponding rise in the temperature of the ventilated flask. If allowance be made for the fluctuations of the room temperature the "heating" curve will be considerably modified, as shewn in Fig. 2, A′. The first and second maxima will both be considerably higher and the fall after the second maximum will be approximately continuous.

On June 2 the two flasks were opened and their contents turned out and examined. In the sealed flask considerable gas pressure had developed. The wheat ran out freely and was not caked or only very slightly so. Though of course very damp and soft it showed no trace of mould or discolouration, but had a fairly strong acid smell and taste and gave a distinctly acid reaction with litmus paper.

In the ventilated flask the grain was very damp, mildewed, caked into an almost solid mass, greatly discoloured, almost black in places, with a very foul ammoniacal smell. In the lower part it was not quite so rotten.

These two experiments demonstrate very conclusively that "heating" of wheat does not take place in hermetically sealed vessels under the conditions given, and it is fairly safe to argue that it could not take place in large masses of grain in air-tight storage. This treatment also prevents the growth of moulds and preserves the wheat from becoming rotten even in the presence of a high excess of moisture,

FIG. 2.


TEMPERATURE (Centigrade)
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DAYS
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75
A
A′
B
C

which was purposely exaggerated in our experiments in order to promote heating.*

It should be noted, however, that the damp wheat in the sealed flasks became distinctly acid, which might seriously impair its milling value. But it is not likely that anybody would attempt to store wheat with the abnormally high moisture content with which we experimented, and there are no grounds for believing that any serious acidity could develop in reasonably dry wheat under the same conditions. Indeed, the Maltese experience communicated to us by Prof. Zammitt goes to show that no evil effects result from air-tight storage [Dendy, 1918]. It is, on the other hand, quite possible that this method would permit of the storage of grain of a higher moisture content than usual, owing to the prevention of heating; but, from other points of view, the limit of safety as regards moisture for wheat intended for prolonged storage in air-tight silos remains to be determined by experiments on a large scale.

Returning to the consideration of the temperature curves of the heating wheat in our two experiments we may emphasize one peculiarity which both exhibit and to which we have already referred. That is the appearance of two maxima, separated by a considerable interval of time. In other words, after the first period of heating there is a fall of temperature, followed by another rise to a higher point than before. It has been suggested to us that this may indicate that two distinct processes of fermentation are involved and we would suggest that while the first is due to enzymes in the grain itself the second may be due to microbic fermentation resulting in the rotting of the wheat. There is obviously room here for further investigations of an interesting character.†

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* In another experiment at room temperature, with wheat having a moisture content of only 19·3 per cent., heating progressed much more slowly, the rise of temperature being only about 3° C. for the first eight weeks. Then, with the advent of warmer weather in June, it began to increase fairly rapidly, rising about 10° C. in nine days. In a sealed companion flask no heating took place.

† Compare Newstead and Duvall [1918].

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